APPENDIX E

COMPUTATION FOR DESIGN OF TRANSITION SECTION
(Illustrative Example)

E-1. Introduction. The following example is presented to illustrate the principles of transition design discussed in paragraph 4-22. The transition considered is located between a two-gate intake gate section and a circular conduit, and the design involves only horizontal convergence. However, the procedure discussed is applicable to transitions having both horizontal and vertical convergences.

E-2. Design Conditions. The example intake gate section consists of two 9- by 20-ft parallel rectangular conduits separated by a 6-ft-thick pier. The downstream conduit is 20 ft in diameter resulting in an area reduction of 12.8 percent. Maximum discharge will be 50,000 cfs. All curves should be selected to effect gradual changes in the direction of flow. The necessary outer wall convergence is formed by reverse curves of equal radii. The pier taper is also curved. The minimum thickness of the tapered pier section has been limited to 2 ft for structural reasons. Tangent extensions from the end of the pier are assumed to enclose a nonflow area, which is believed to be realistic. The end of the pier is blunt to ensure a stable point of separation of the flow from the pier. The fillet design conforms to circular quadrants of varying radii to accomplish the required geometric change from rectangular to circular and to provide a gradual area reduction. The general transition layout is shown in plate E-1.

E-3. Design Computations. Transition designs are generally based on simple curves and tangents which result in relatively easy but laborious design computations. Therefore, detailed computations are omitted from this illustration but the general procedure and equations are included as a guide.

E-4. Convergence Computations.

a. Area Reduction. The percent area reduction is computed by the following equation:

$$\Delta A \text{ (percent)} = 100\left(1 - \frac{A_d}{A_u}\right) = 100\left(1 - \frac{314}{360}\right) = 12.8\% \qquad \text{(E-1)}$$

where

A_d = downstream circular conduit area

A_u = upstream total gate section area

b. Transition Length. The required transition length (L_T) is based on flow conditions and a limiting angle of contraction by the more conservative of the computations:

$$L_T = (R_u - R_d)\left(\frac{V}{\sqrt{gD}}\right)$$

$$= (15.62 - 10)\left[\frac{149}{\sqrt{32.2\ (20.70)}}\right] = 32.4\ \text{ft} \qquad \text{(E-2a)}$$

where

$R_u - R_d$ = maximum radial offset from the outside boundary upstream to the corresponding location in the conduit boundary downstream

V, D = average of the velocities and equivalent area diameters at the upstream and downstream end of the transition (139 and 159 fps; 21.41 and 20 ft)

$$L_T = \frac{(R_u - R_d)}{\tan\ \theta} = \frac{(15.62 - 10)}{0.1228} = 45.8\ \text{ft (use 46 ft)} \qquad \text{(E-2b)}$$

where θ is the maximum allowable angle of contraction of the boundary relative to the conduit axis (use $\theta = 7°$).

c. Wall Curves. The sidewall transition curves are composed of reverse circular arcs of equal radii and therefore are defined by the equation:

$$r_W = \frac{X_{PRC}^2}{2e} + \frac{e}{2} = \frac{(23)^2}{2(1)} + \frac{1}{2} = 265\ \text{ft} \qquad \text{(E-3)}$$

where

r_W = wall curve radius

X_{PRC} = conduit center-line distance PC to PRC or PRC to end of transition ($=L_T/2$)

e = one-half of convergence of one wall from PC to end of transition

d. Pier Curves. The pier curves are also composed of circular arcs of equal radii and are based on equation E-3 (with $e = 1.5$ ft in example). Additional computations are required to locate the pier curve PT where the minimum pier thickness is 2 ft. In these computations the curve (r_p) is considered to start at the conduit center line at the end of the transition and extend upstream to (X_{PT}) to the point where the example value of e is 1 ft.

e. Tangent Extension. The slope of the tangent extension ($\tan \theta_P$) and its intersection with the conduit center line are required for the area computations and may be computed using the following equations:

$$\tan \theta_P = \frac{X_{PT}}{r_p - e} \quad \text{(E-4)}$$

$$X_T = \frac{e}{\tan \theta_P} = \frac{(r_p - e)\, e}{X_{PT}} \quad \text{(E-5)}$$

where

r_p = radius of pier curve

X_{PT} = conduit center-line distance from pier PT to end of transition

e = 0.5 minimum pier thickness

X_T = conduit center-line distance from pier PT to the intersection of the tangent extension and the conduit center line

E-5. Area Curves. The development of a transition area curve requires area computations at cross sections normal to the transition center line. These sections are usually selected close together at the beginning and end of the transition to accurately define the curve in the region where the slope of the curve is approaching zero. The shape of the curve depends upon the horizontal and vertical convergences of the outer walls and the taper of the pier as well as upon the radii of the quadrant fillets. When the horizontal and vertical convergences are fixed (plate E-1), an area curve for the converging rectangular sections (plate E-2) is helpful in designing the fillets which result in the final transition area curve. Several trial fillet designs are usually required in the development of a satisfactory curve.

a. Areas of Converging Rectangular Sections. The computation of the areas of the converging rectangular sections requires determination of the distances of the walls, pier surface, and tangent extension from the conduit center line at the selected sections. The curve and tangent extension equations previously discussed can be used for these computations. The total flow width at each section is multiplied by the transition height to obtain the cross-sectional area. With vertical convergence the appropriate height at each section is used. The resulting areas are plotted as shown in plate E-2.

b. Fillet Quadrant Design. The design of the quadrant fillets necessitates the determination of fillet radii that will adjust the converging rectangular sections to provide a smooth, gradually changing area curve as well as result in gradual changes in the direction of flow along the fillets. Preliminary computations based on uniform variation of the fillet radius from zero at the beginning of the transition to the conduit radius at the end of the transition are helpful in developing final radii for the fillets. A satisfactory area curve was obtained by use of nonuniformly varying fillet radii defined by circular arcs near the upstream and downstream ends of the transition and uniformly varying radii in the middle section, as shown by the fillet radius plot in plate E-2. Tangent distances of 2 and 5 ft, selected for the upstream and downstream arcs, respectively, resulted in a slope of 0.25641 on 1 for the uniformly varying radius curve. The fillet radius (r_f) for each section was then computed using the following equation:

Upstream arc

$$r_f = r_a - \left(r_a^2 - x^2\right)^{1/2} \qquad \text{(E-6)}$$

Downstream arc

$$r_f = \frac{D}{2} - \left\{ r_a - \left[r_a^2 - \left(L_T - x\right)^2 \right]^{1/2} \right\} \qquad \text{(E-7)}$$

Uniformly varying fillet radii

$$r_f = \text{slope (x - tangent length of upstream arc)} \qquad \text{(E-8)}$$

where

r_f = fillet radius

r_a = arc radius

x = center-line distance from beginning of transition

c. <u>Fillet Area.</u> The full fillet area to be subtracted from the rectangular cross-sectional area is computed by the equation

$$A_f = 0.8584\ r_f^2 \qquad \text{(E-9)}$$

where

A_f = fillet area

r_f = fillet radius

The final transition area curve is shown in plate E-2. This curve has a zero slope at both ends of the transition. The slight irregularity in the curve near the downstream end results from use of the tangent extensions in the area computations rather than theoretically extending the pier curve to the end of the transition.

E-6. <u>Fillet at 45-Deg Point.</u> The change in direction of flow along the 45-deg points of the fillets should be smooth and gradual. The path of the flow is three-dimensional and cannot be readily illustrated. However, examination of the locus of the 45-deg point in the horizontal (X) plane and the vertical (Y) plane is helpful in judging the smoothness and rate of change in direction. Such a plot referenced to the conduit center line is shown in plate E-2 and indicates a smooth and gradual change in the direction of flow. Computation of the coordinates (X and Y) of the 45-deg points (Point C on Section C-C, plate E-2) is accomplished using the following relations:

$$c = r_f \text{ versine } 45° \qquad \text{(E-10)}$$

$$x = 0.5t_w - c \qquad \text{(E-11)}$$

and

$$y = 0.5t_h - c \tag{E-12}$$

where

c = horizontal or vertical distance from corner of local rectangular section

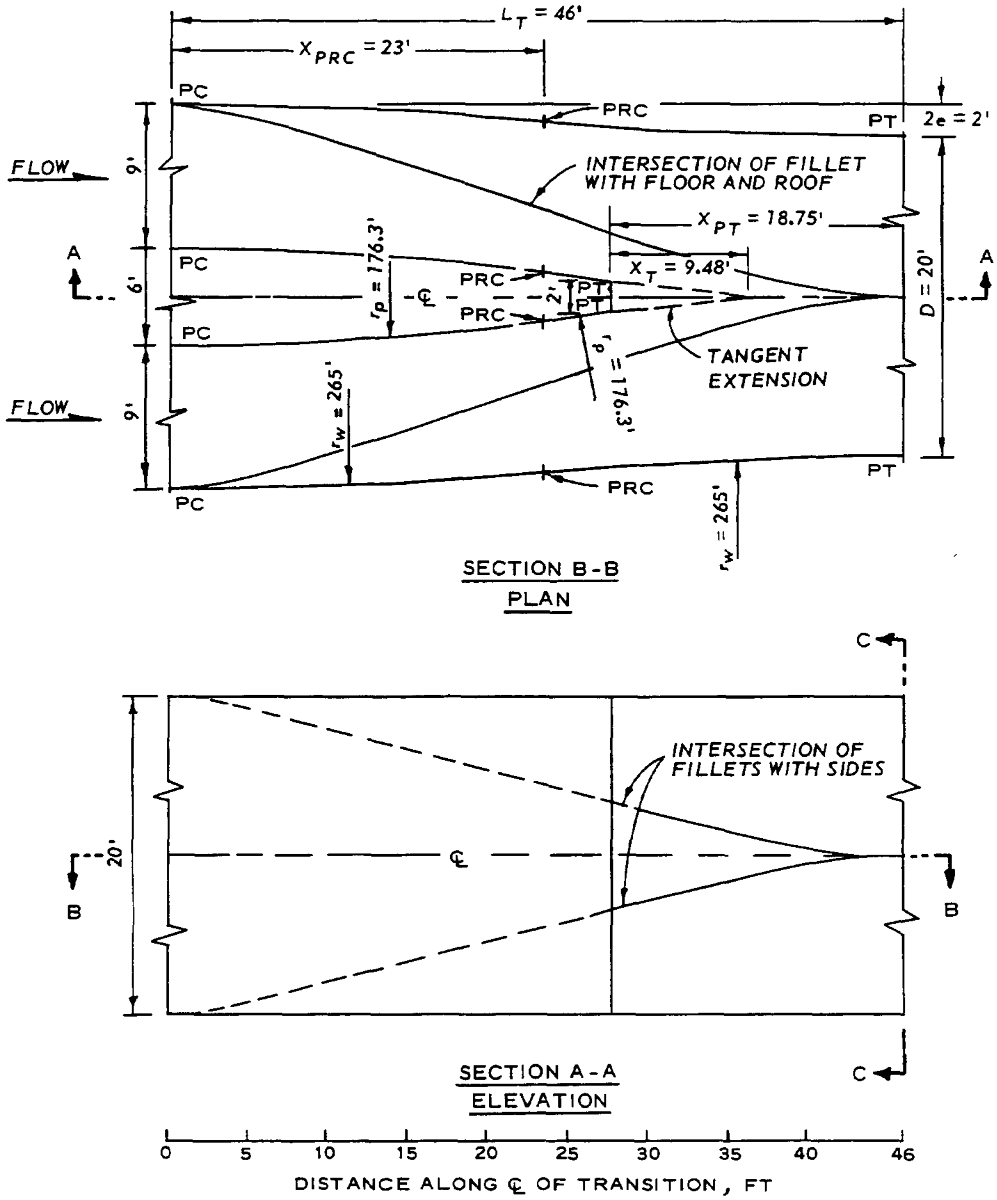
r_f = local fillet radius

t_w = local transition half width

t_h = local transition half height

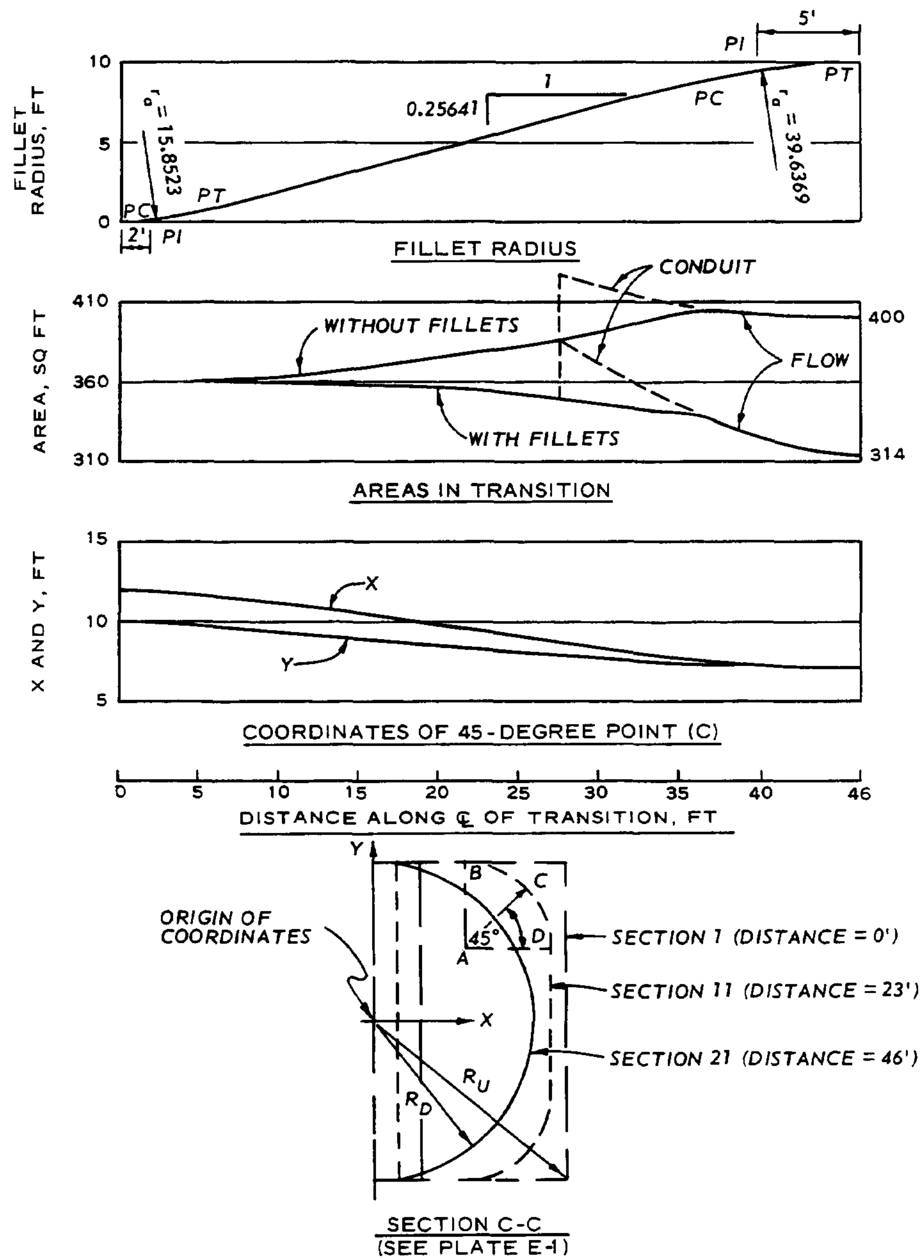
E-7. Transition Pressures. General pressure conditions throughout the transition can be computed by examination of the change in velocity head from section to section. However, local pressure conditions can only be investigated by means of a model study. Model experience indicates that undesirable pressure conditions may exist immediately downstream from the transition unless the transition is carefully designed. These conditions result from the relative outward flare of the boundary as it changes from converging to straight.

E-8. Layout Data Information. Plates E-1 to E-3 illustrate transition drawings and data pertinent to review of transition designs and to field construction. Plate E-1 illustrates the general transition layout and fillet intersections with the sides and floor of the transition. Plate E-2 shows graphically the variations in the fillet radii, the transition area, and the locus of the fillet 45-deg point. Superimposed upstream, middle, and downstream transition sections are also shown in this plate to illustrate the geometric changes from section to section and to identify data tabulated in plate E-3.



SEE PLATE E-2 FOR SECTION C-C.

EXAMPLE TRANSITION LAYOUT



EXAMPLE
TRANSITION
CHARACTERISTICS

COORDINATES OF POINTS IN FIRST QUADRANT											
SECTION	DISTANCE ALONG CENTER LINE OF TRANSITION FT	LENGTH OF FILLET RADIUS FT	HALF-WIDTH OF PIER FT	POINT A		POINT B		POINT C		POINT D	
				X FT	Y FT	X FT	Y FT	X FT	Y FT	X FT	Y FT
1	0	0	3.0000	12.0000	10.0000	12.0000	10.0000	12.0000	10.0000	12.0000	10.0000
2	1	0.0316	2.9972	11.9665	9.9684	11.9665		11.9888	9.9907	11.9981	9.9684
3	2	0.1267	2.9887	11.8657	9.8733	11.8657		11.9553	9.9629	11.9924	9.8733
4	3	0.2865	2.9748	11.6965	9.7135	11.6965		11.8991	9.9161	11.9830	9.7135
5	4	0.5128	2.9548	11.4570	9.4872	11.4570		11.8196	9.8498	11.9698	9.4872
6	6	1.0256	2.8983	10.9065	8.9744	10.9065		11.6317	9.6996	11.9321	8.9744
7	10	2.0513	2.7174	9.7599	7.9487	9.7599		11.2104	9.3992	11.8112	7.9487
8	14	3.0769	2.4457	8.5530	6.9231	8.5530		10.7287	9.0988	11.6299	6.9231
9	18	4.1026	2.0828	7.2854	5.8974	7.2854		10.1864	8.7984	11.3880	5.8974
10	21	4.8718	1.7504	6.2948	5.1282	6.2948		9.7397	8.5731	11.1666	5.1282
11	23 (PRC)	5.3846	1.5000	5.6154	4.6154	5.6154		9.4229	8.4229	11.0000	4.6154
12	25	5.8974	1.2496	4.9360	4.1026	4.9360		9.1061	8.2727	10.8334	4.1026
--	27.25	(END AND PT OF PIER)									
13	28	6.6666	0.9155*	3.9454	3.3334	3.9454		8.6594	8.0474	10.6120	3.3334
14	32	7.6923	0.4885*	2.6778	2.3077	2.6778		8.1171	7.7470	10.3701	2.3077
15	36	8.7179	0.0616*	1.4709	1.2821	1.4709		7.6354	7.4466	10.1888	1.2821
--	36.73	(END OF TANGENT EXTENSION)									
16	40	9.5432	0	0.5247	0.4568	0.5247		7.2728	7.2049	10.0679	0.4568
17	42	9.7976		0.2326	0.2024	0.2326		7.1606	7.1304	10.0302	0.2024
18	43	9.8863		0.1307	0.1137	0.1307		7.1214	7.1044	10.0170	0.1137
19	44	9.9495		0.0581	0.0505	0.0581		7.0935	7.0859	10.0076	0.0505
20	45	9.9874		0.0145	0.0126	0.0145		7.0767	7.0748	10.0019	0.0126
21	46	10.0000	0	0	0	0	10.0000	7.0711	7.0711	10.0000	0

* BASED ON TANGENT EXTENSION.

NOTE:

COORDINATES OF POINTS IN OTHER QUADRANTS CAN BE OBTAINED BY APPROPRIATE CHANGES OF THE SIGN OF THE TABULATED VALUES.

SEE PLATE E-2 FOR DEFINITION SKETCH.

EXAMPLE TRANSITION
SECTION COORDINATES